# A Mini Study of Voltage, Current, and Resistance

Power for our stations is a "hot" topic among our readers. So this month, we take a behind-the-scenes look at that stuff called "electricity" for a better understanding of...How It Works.

After shifting focus for a few months to study some special image-enhancing mics and keys, we're back on the path of explaining electronic theory for amateur radio in easy-to-understand terms. Yes, and our long-range plans include discussions of everything from vacuum tubes and transistors to transceivers and linear amplifiers, and more. In addition, a few more side excursions and some neat topic-related homebrew projects are slated for inclusion along the way, just for fun. You will love them. Honest!

***"[Having] this basic knowledge will give you an advantage in the increasingly overlooked area of RF design and wireless communications....Soon, individuals with knowledge and hands-on experience in these areas will be in a position to name their own salaries."***

The overall results should prove quite beneficial for both visualizing how your gear works and preparing for future license exams to upgrade. Further, this basic knowledge will give you an advantage in the increasingly overlooked area of RF design and wireless communications. Today's colleges and technical institutes are focusing on what the public considers big-money careers, namely digital electronics and computers. This is leaving a wide gap in the areas of analog technology and RF design. Soon, individuals with knowledge and hands-on experience in these areas will be in a position to name their own salaries. Being a radio amateur in today's world can truly have its rewards!

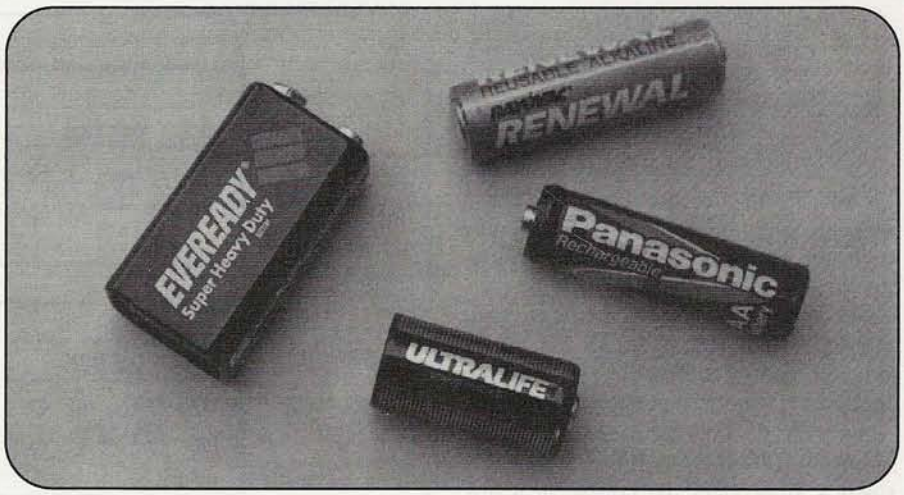


*Photo A. DC electricity is typically stored in chemical form by batteries and released when a closed circuit is connected to its output terminals. DC is most efficiently stored in low-voltage and high-current form and used near its physical location to minimize wire losses.*

This month's column establishes a solid foundation on which we'll build and expand in the upcoming months. It's also an introduction to next month's discussion of vacuum tubes and transistors which, in turn, is a prelude to a future column on transceivers. Now let's begin with a quick look at some familiar basics.

## AC and DC, a Quick Review

As you know, there are two distinct types of electrical current: DC, for Direct Current, and AC, for Alternating Current. DC has a specific polarity and always flows from negative (-) to positive (+), assuming, naturally, that a complete circuit or two connections are present. DC is stored in chemical form in cells or batteries of cells (Photo A), or it may be produced by solar cells, or by *rectifying* and *filtering* AC into DC. AC does not have set positive and negative polarities or connections/terminals; it flows alternately in both directions. How frequently it changes directions/polarizes is expressed as its *frequency*, measured in Hz, kHz, MHz, etc. AC is usually produced by generators, but it can also be derived or synthesized from DC by using a "chopper" circuit to change its polarity.

When AC is applied to a coil, it produces a magnetic field that continuously changes in polarity or direction. If a sec-

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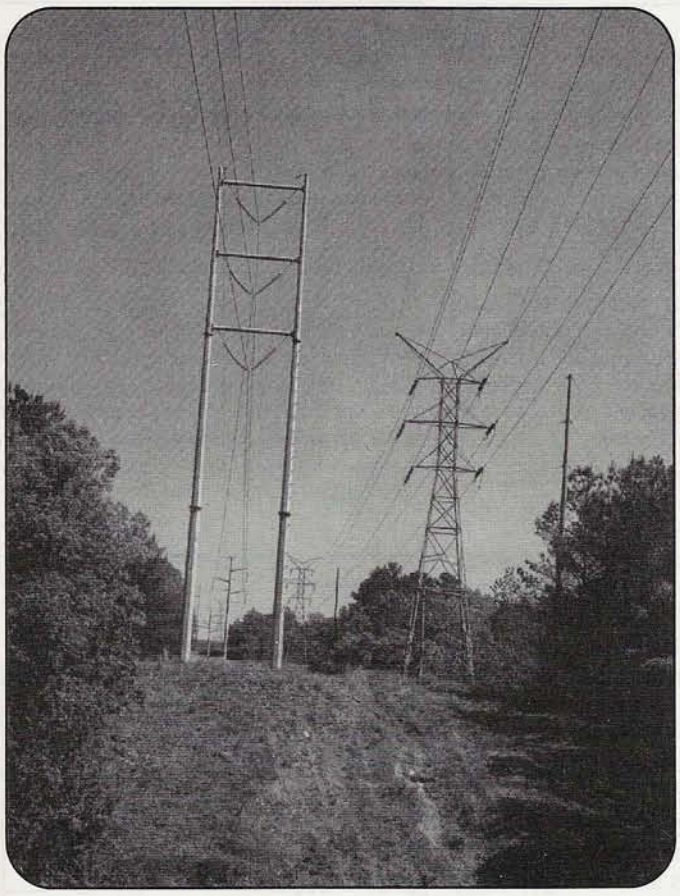

*Photo B. AC electricity is normally produced by huge generators at dams near lakes or waterfalls, then transferred over long distances by high power lines dotting our countryside, like those shown here.*

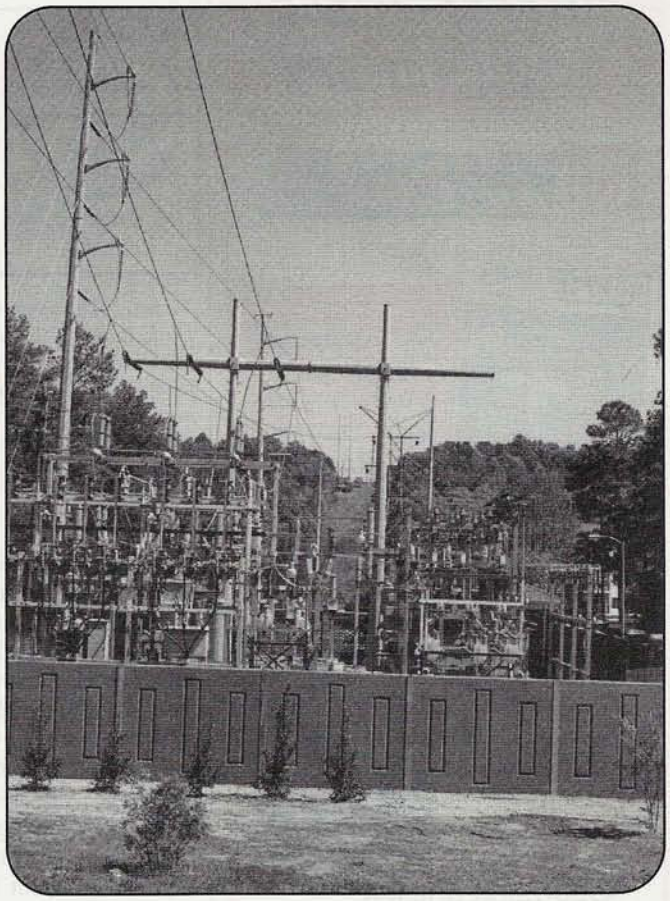

*Photo C. AC power is most effectively transferred between cities in high-voltage and low-current form, then stepped down to lower voltage at high current by transformers in substations, like the one shown here, for distribution in local areas and neighborhoods.*

ond coil is placed in close proximity to the first coil, *transformer action* will cause a voltage to be *induced* in the second coil. The amount of voltage induced into that secondary coil will depend on the transformer's *turns ratio*. Assuming a ratio of 4:1, a primary coil of 200 turns, a secondary coil of 50 turns, and 480 volts at 1 ampere applied to the primary coil, output from the secondary coil will be approximately 120 volts at 4 amperes ($^1/_4$ the voltage at 4 times the current). Theoretically, that equates to 480 watts input (480 volts x 1 ampere) and 480 watts output (120 volts x 4 amperes). In reality, output will be closer to 120 volts at 3.9 amperes (468 watts), with 12 watts dissipated as heat. Everything in electronics equates. There is no hidden magic.

Incidentally, when DC is applied to a coil, it produces only a stationary magnetic field and becomes an *electromagnet*. Have you ever noticed those large cranes lifting autos in salvage yards? The crane's large pickup disk is nothing more than a huge electromagnet.

Since AC power is often generated near dams or in other out-of-the-way places, it is *stepped up* to a higher voltage at lower current for more efficient transmission between geographical areas or cities. Some rural power lines carry 14,000 to 17,000 volts (Photo B). In cities, power substations containing large transformers then step the voltage down and the current up for distribution in parallel-connected neighborhoods (Photo C).

Radio signals are also AC voltages, which are produced by *oscillator circuits* in communications equipment. The difference between these AC voltages and those distributed by power lines are their frequencies and power levels. AC for home and office (utility) power is 60 Hz at levels greater than 1 volt. AC signals transmitted through the air—radio waves—are on frequencies between 300 kHz and several GHz, at levels below 1 volt (millivolt and microvolt range). Aren't you glad you followed our discussion of metric measures a few months ago in this column?

## Voltage, Current, and Resistance Simplified

One of the first applications of electronic theory we learn when studying for an amateur radio license is the interrelation of voltage, current, and resistance, or Ohm's Law (Figure 1). We use its associated formula to solve several of the test questions on license exams of all classes and to calculate numerous technical details of circuits.

Now let's take a closer look at each of its associated variables (which will prove even more beneficial when we study vacuum tubes, transistors, and transceivers). *Voltage* is a level or amount of *electronic pressure* or *force* and is measured in *volts*. *Current* is the *quantity of electrons*

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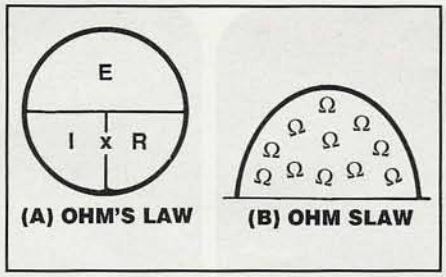


*Figure 1. The three variations of Ohm's Law, I = E/R, R = E/I and E = I x R, are all combined in this easy to remember and use circle formula ("A"). The dish in "B" is a different matter! Ohm Slaw is similar to Alaskan mush, except different.*

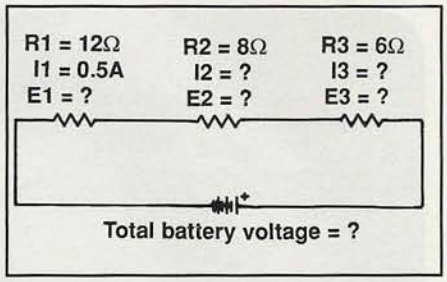


*Figure 2. A series circuit is characterized by its single path for current flow. Also in a series circuit, current is the same through each component while voltage divides. Use those facts plus Ohm's Law to calculate our missing values. Then assume each resistor is 10 ohms, the battery is 180 volts, and repeat your calculations. Compare your answers with the text.*

moved by an applied pressure or voltage and is measured in *amperes*. *Resistance* is the *opposition to current flow* and is measured in *ohms*. Every circuit exhibits some amount of resistance. The greater that resistance, the less the current flow in the circuit, and vice versa.

One quite effective means of visualizing these "big three" parameters is by making an analogy to a more tangible substance or quantity, such as water. In this case, current is akin to a particular amount of water moving through a pipe, voltage is comparable to the force pushing that amount of water, and resistance is analogous to the size of the pipe or hose through which the water must flow. The larger the hose's diameter, the lower its resistance and the more water it will pass in a given length of time. The smaller the hose's diameter, the higher its resistance and the less water it will pass in that same amount of time. Similarly, a low-resistance circuit (like a closed switch or conducting tube or transistor) will pass much more current than an open circuit (or non-conducting tube or transistor).

A fourth unit of measurement, *power*, also warrants mention at this point. Power is used to describe an *amount of energy* and is typically specified in *watts*, which, in turn, is the product of *voltage times current* (E x I) for input power, or *current squared times resistance* ($I^2$ x R) for output power. A primary law of physics states that energy cannot be created or destroyed, but only changed in form. Applying that law to amateur radio, we can say everything from a transformer (which converts one voltage to another) to a handheld FM transceiver (which converts battery power to intelligence-modulated RF power) is an energy converter.

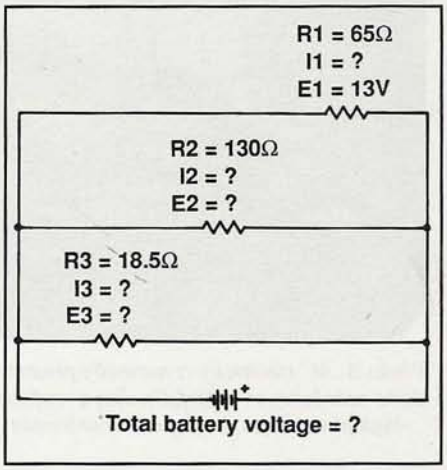


*Figure 3. A parallel circuit is characterized by its multiple paths for current flow. Also in a parallel circuit, voltage remains the same across each component while current divides. Use Ohm's Law to calculate missing values, then assume each resistor is 12 ohms, the battery is 12 volts, and repeat your calculations. Compare your answers with the text.*

Yes, and regardless of what form of energy is being converted, there is always some resistance or loss between input and output that is dissipated as heat or some other form of energy.

As a real-life example, let's say we use a 13.0-volt/8-amp DC power supply with our 50-watt 2-meter rig for home operation. Input power to the DC supply is 120 volts AC times 1 amp (approximate), or 120 watts. Output from the DC supply is 13 volts at 7 amps, or 91 watts, which, in turn, is the input power required for the 2-meter rig to produce 50 watts output. The difference between the DC supply's 120 watts in/91 watts out (29 watts worth) is dissipated as heat in the transformer

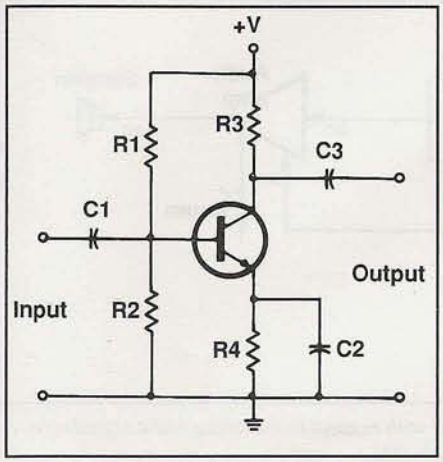


*Figure 4. This "streamlined" version of an RF amplifier circuit illustrates how it is equivalent to five resistances wired in a combination series-parallel circuit. Where is the fifth resistor? It is the internal emitter-to-collector resistance of the transistor itself...and its resistance changes according to the input signal. More details next month!*

and output/regulator transistor. The difference between the rig's input and output (41 watts) is likewise dissipated as power transistor/heatsink loss. As I pointed out earlier, everything in electronics equates, or balances out. (*You can also see that the power supply uses energy more efficiently than the radio.—ed.*)

## Series and Parallel Circuits

Whether a transceiver (or any piece of electronic equipment) is solid state or vacuum tube, all-mode or FM-only, its inner workings are comprised of numerous *series* and *parallel* circuits. Visualizing how these circuits work plays an important role in understanding how related equipment works. In light of that, let's quickly discuss some series and parallel circuits (plus consider how our simple circuits can also represent stages in gear as "seen" by its power supply, etc.).

Let's begin by pointing out and comparing the differences in series and parallel circuits, as illustrated in Figures 2 and 3. Notice a series circuit has only one path for current flow, whereas a parallel circuit has two or more paths for current flow. If the path is broken or a resistor opens in a series circuit, the complete circuit stops working. If a path or resistor opens in a parallel circuit, only the open branch stops working. A series circuit might be compared to a string of old-fashioned Christmas tree lights: if one goes out, they all go out. Lights wired in parallel are the opposite: when one goes out, the rest stay lit.

Now refer to Figure 2, and commit the following facts of life to memory—*for* life. *In a series circuit, total resistance is always equal to the sum of all the resistances ($R_T = R_1 + R_2 + R_3$, etc.) and is always greater than the highest value resistor.* In Figure 2, that means $R_T$ will always be more than 12 ohms. Also in a series circuit, *VOLTAGE DIVIDES among the resistances while current stays the same* (current is our "reference factor"). Additionally, *the highest measured voltage drop will be across the highest resistance.* Finally, if we know two parameters of a circuit or any of its components, we can use Ohm's Law to calculate the third/unknown parameter.

Next, *in a parallel circuit, total resistance is equal to the reciprocal of the resistances,*

$$RT = \frac{1}{\frac{1}{R1} + \frac{1}{R2} + \frac{1}{R3} \ldots}$$

*and is always less than the lowest value resistor.* In Figure 3, that means $R_T$ must be less than 18.5 ohms. Also, *in a parallel circuit, CURRENT DIVIDES among the resistances while voltage stays the same* (voltage is our "referencing factor"). Additionally, *the most current will flow through the lowest resistance*, just like our previously discussed water analogy. Yes, and once again, Ohm's Law works for calculating unknown parameters.

***"AC for home and office (utility) power is 60 Hz at levels greater than 1 volt. AC signals transmitted through the air—radio waves—are on frequencies between 300 kHz and several GHz, at levels below 1 volt (millivolt and microvolt range)."***

Now for clarification and practice, let's calculate the unknown parameters in Figure 2. Since $R_1$ is 12 ohms and passes 0.5 amps, the voltage across it must be 12 x .5, or 6 volts. Since current is the same in a series circuit, $R_2$ and $R_3$ must


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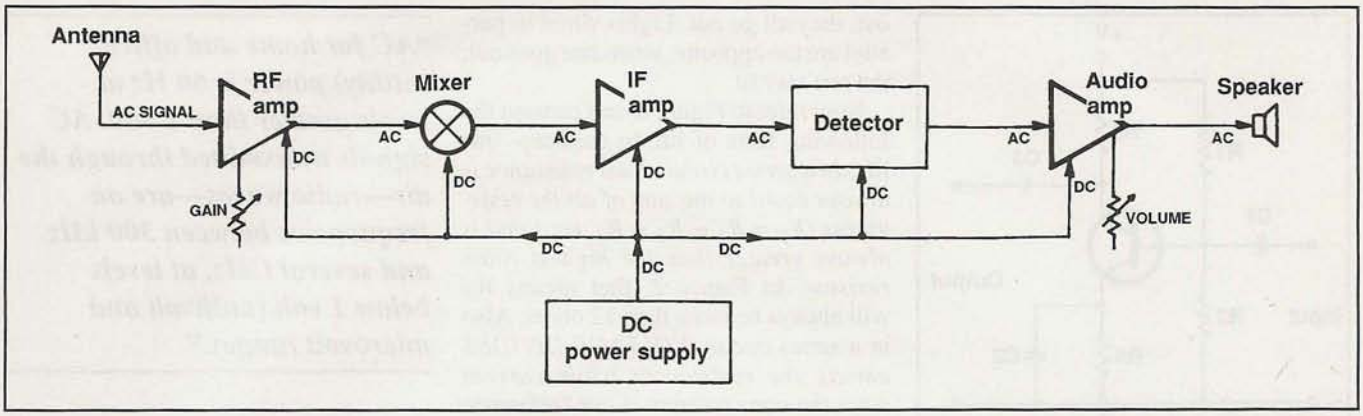


*Figure 5. This simplified block diagram of a radio illustrates how its stages are series-connected with respect to incoming radio signals (AC), but wired in parallel with reference to its DC power supply (DC).*

also be passing 0.5 amp. $R_2$ is 8 ohms, so 8 x 0.5 = 4 volts. $R_3$ is 6 ohms, so 6 x 0.5 = 3 volts drop across it. Total battery voltage ($E_T$) must thus be 6 + 4 + 3, or 13 volts. We can double-check this by multiplying $R_T$ (total resistance, 12 + 8 + 6) times $I_T$ (total current, 0.5). If 26 x .5 = 13, we are correct. If desired, incidentally, we can also multiply $E_T$ (13) times $I_T$ (.5) to tally total power (6.5 watts).

Now, suppose all three resistors in Figure 2 are 10 ohms each. What will be the total resistance? You're right, 30 ohms. Assume the applied voltage is 180 volts: what will be the current through $R_3$? Yup, 6 amps—the same as $R_1$ or $R_2$—because it's a *series circuit.*

Next, let's calculate the unknown parameters in Figure 3. Since $R_1$ is 65 ohms and 13 volts are across it, the current through $R_1$ is 13 divided by 65, or .2 amp. Voltage is the same in all branches of a parallel circuit, so $R_2$ and $R_3$ must also have 13 volts across them, and that will also be E total. $R_2$ is 130 ohms, so 13/130 = .1 amp. $R_3$ is 18.5 ohms, so 13/18.5 = .7 amp. I total is thus .2 + .1 + .7, or 1 amp. R total is 13/1 or 13 ohms (I will let you double-check it using the reciprocal formula. You should tally 13.0 ohms).

Now suppose all three resistors in Figure 3 are 12 ohms each. Quick, what will be the total resistance? It's easy. Since all values are equal, it's 12 ÷ 3, or 4 ohms). If applied voltage is 12 volts, what is the total current? Say 12/4 is 3 amps, and you are right. If you said 1 + 1 + 1 = 3 amps, you are also right.

***"A primary law of physics states that energy cannot be created or destroyed, but only changed in form."***

Silly calculations, you say. Not at all! With a few value changes, the three resistors in Figure 2 could easily represent the DC-equivalent circuit for a transistor amplifier. The three resistors in Figure 3 could also represent parallel-connected loads or stages in a rig as "seen" by its DC power supply. Every little piece of information we're sharing with you is beneficial now and for years hence.

We're almost out of space, so I'll close by quickly sharing two real-life examples of series and parallel circuits in actual use (Figures 4 and 5), then continue expanding our studies next month. Fair enough?

## Conclusion

Some readers may say this month's column almost hit the "too complex" level, some may say it was almost too basic, and others might think it was almost boring. *Heads up, all three groups!* Remember what I said earlier. We're only at the beginning; we're establishing a solid background and a foolproof way to understand electronic circuits. Stick with me. The discussions will get even more interesting, and you'll eventually become a sharp Tech! 73,

—Dave, K4TWJ


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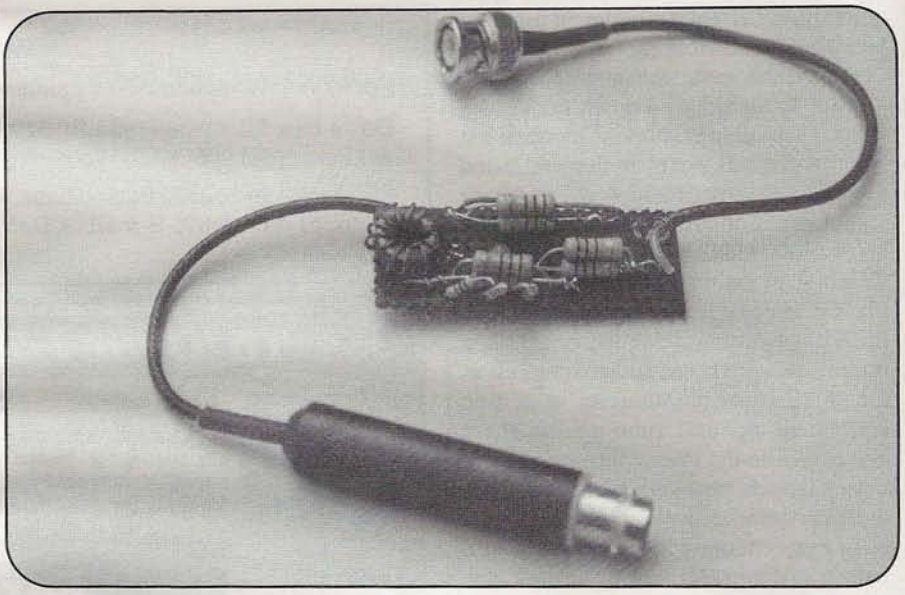
CIRCLE 62 ON READER SERVICE CARD

# A Mini Study of Voltage, Current, and Resistance—Part 2

Before moving into vacuum tubes and transistors, Dave decided to cover a bit more ground on the basics of series and parallel circuits—and he shows you how to build a unique SWR checker.

During a quick review of last month's column, I realized some additional aspects of AC, DC, series, and parallel circuits warranted further discussion before continuing on to tubes and transistors. So I'm interjecting Part 2 with some vital, yet often-overlooked, information hams are assumed to know simply because they're licensed (we may be sharp, but we're not *that* sharp!). It doesn't explain all the fine points of analyzing circuits, etc. (that's not possible in three, four, or even five columns!), but it is an "expandable" start in the right direction.

Let's pick up from the close of last month's column and continue with a quick study of combination series and parallel circuits. We'll then trace current paths in some often-used circuits, clarify some of the "why and how" logic in circuit operations, and wrap up with an experimental four-resistor SWR bridge that can be adapted to fit your needs. Sound interesting? Let's get started!



*My homebrewed Wheatstone bridge SWR checker. The little critter works on the principle of measuring resistance rather than reactance. That is, a 50-ohm antenna exhibits a 1:1 SWR, a 75- or 37-ohm antenna exhibits a 1.5:1 SWR, and a 100- or 25-ohm antenna exhibits a 2:1 SWR. This follows the circuit in Figure 6, so it has an LED (barely visible in the photo) instead of a meter.*

## Combination Series and Parallel Circuits

Studying basic series and parallel circuits is a superb exercise in understanding how more complex circuits in electronic equipment work. In fact, the more we compare on-paper circuits with in-cabinet rigs, the more we realize they're one and the same. This is vividly illustrated in Figure 1. At first glance, it just looks like a license exam test question with no obvious connections to the "real world." Looking closer, however, we see that it represents the DC equivalent to circuitry in a mobile or handheld transceiver. How so? Resistor R1 is electrically equivalent to the transmitter's final power amplifier stage. It has the battery's full 13 volts applied to it and, because it's wired in parallel with other circuitry, can draw its required current without affecting other stages (the fact that current divides in parallel and voltage divides in series, incidentally, was discussed in last month's column).

Resistors R2 and R3 represent other stages in the transceiver, possibly its receiver's RF amplifier and local oscillator. Where are the other stages? They might also be combined and represented with R2 and R3, omitted for simplicity of discussion, or they might be connected as additional and unshown circuits. Finally, R4 represents a voltage regulator that drops the voltage to the RF amplifier (R2) for wide dynamic range, while minimizing voltage variations felt by the local oscillator (R3), thus ensuring good frequency stability. Resistors/stages R2 and R3 draw the same amount of current, so they can be wired in parallel and the combination connected in series with voltage

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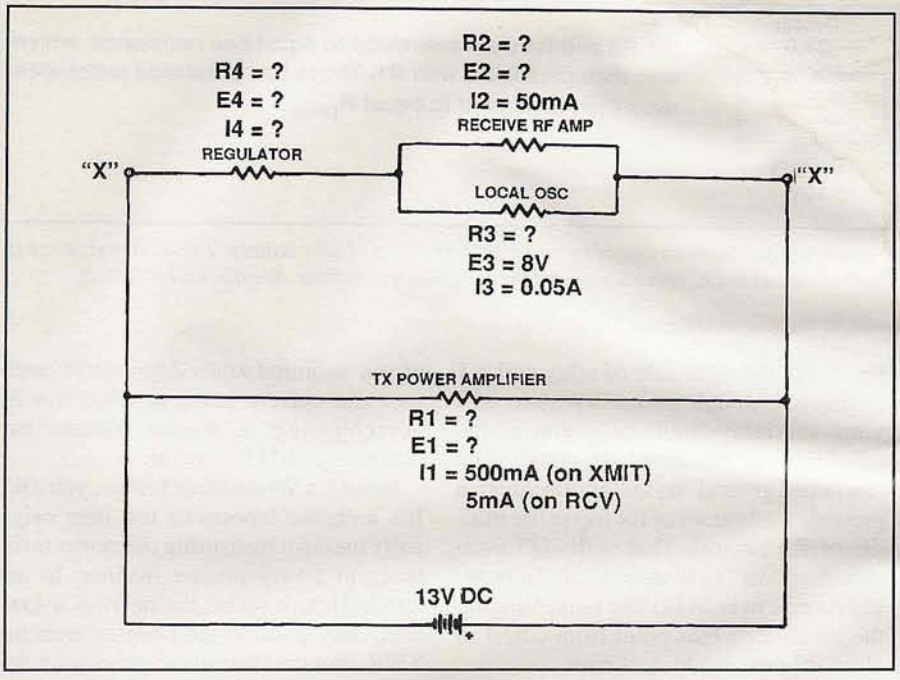



*Figure 1. Combination series-parallel circuit representing various stages of a transceiver, as discussed in text. Try your skill at calculating the unknown values (it's possible!). Just start at R3 and work your way through the circuit. Then compare your answers with the text.*

regulator (R4). That's assuming, naturally, that R4 can safely pass the current required for both R2 and R3.

Wow—there was a wealth of good practical electronics information in those last few sentences. Read them again to get their full impact.

Now let's calculate some missing values and watch the circuit in (electrical) action. During transmit, R1 draws 500 milliamps (mA). Applying Ohm's Law, we see that R = E (13 volts)/I(.5 amp) and yields an equivalent resistance of 26 ohms. On receive, R1 draws only 5 mA (13 volts/.005 amps) to yield an equivalent resistance of 2600 ohms. As we learned last month, the lower a circuit's resistance, the more current it will pass or use (and vice-versa).

Now look at R2 and R3. Since they're in parallel, the voltage across each is 8 volts. Since they're in series with R4, the voltage across R4 must be 13 minus 8, or 5 volts. Following? Now, since R2 and R3 each draw 50 mA, their individual resistances must be 8 volts/.05 amp, or 160 ohms. R2 and R3 are parallel and of equal value, so their combined resistance is half of 160, or 80 ohms. Let's quickly check to determine if this is correct. R2 and R3 have now been simplified to a single resistor of 80 ohms with 8 volts dropped across it, so 8/80 = .1 amp (which coincides with .05 amp for each resistor). It's right!

Can you now calculate the resistance and voltage across R4? Here's the technique: since R2 and/or R3 drop 8 volts, 5 volts remain to be dropped across R4. Since current is the same in (branches of) a series circuit, 100 mA (the total for both R2 and R3) must pass through R4. So, 5 volts/.1 amp = 50 ohms. Let's double check our calculations from another angle (between points "X" and "X"). Total current is 13 volts/50 ohms plus 80 ohms. That equals 13 volts/130 ohms, which equals .1 amp. It's right.

Next, let's redraw the same circuit in a slightly different manner (Figure 2). But this can't be the same as Figure 1, you say; the battery is in the middle, part of its current goes left, part of its current goes right, and those two parallel resistors are only on the right leg. Look again, friends. There were two current paths in Figure 1 and the two parallel resistors were only in one leg—the one with R4, the "regulator." Current flows the same whether a circuit is drawn horizontally or vertically (though it sure looks different!).

Finally, let's simplify Figure 1 (or Figure 2) to a single resistance, as "seen" by its battery or power source (Figure 3). As stated earlier, R1's resistance is 26 ohms during transmit, and the combined total of R2, R3, and R4 is 130 ohms. Using the (long) formula

$$\frac{1}{\frac{1}{R1} + \frac{1}{R2}}$$

we enter 1/26 = .0384615 + 1/130 = $7.692307692^{-3}$. Add together the two long decimals (you should get .04615380769231), and then take the reciprocal of that sum (1 divided by the total above) and the answer is 21.66 ohms. Double checking, 13 volts /.6 amps also equals 21.6 ohms. This single resistance is what the battery "sees" on transmit. Now check your technical expertise by calculating the single resistance equivalent for receive and look near the end of this column to check your answer.

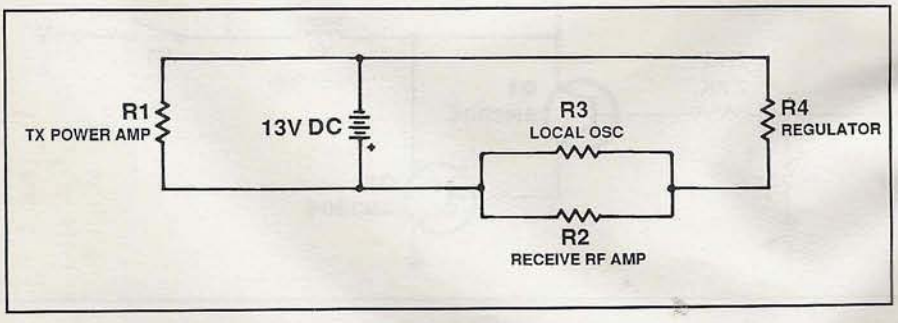



*Figure 2. Here, we redrew the circuit of Figure 1 in a slightly different manner to illustrate how actual wiring in a rig can seem different from its paper diagram.*

## The Fine Art of Tracing Circuits

Once you acquire a "knack" for studying schematic diagrams and tracing circuits, visualizing how a rig, or a circuit within a rig, works becomes a quite informative and eye-opening pursuit. Not all schematics and circuits are easy to follow and understand, however, but a few "brain teasers" along the way just keep us on our toes will help.

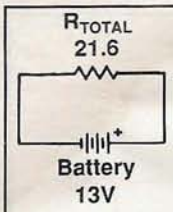
Consider, for example, the partial circuit diagram of a small linear amplifier shown in Figure 4. Let's focus on the amplifier's T/R switching arrangement (mainly because we've only covered ground-floor theory so far; we'll discuss actual amplifier circuitry in more detail later). Looking at this unit's manual, its theory of operation is described in the following paragraph:

An input signal appearing at J2 is voltage-doubled by C7, C8 and C9, then applied to the Darlington pair of Q1 and Q2. These transistors, in turn, activate K1 which switches the amplifier circuit in line during transmit. When Q2 enables K1, it also activates Q3. This shifts the amplifier's bias from cutoff to linear mode operation.

OK gang, now let's go back and fill in some blanks in that story.

One alternation of an incoming (AC) signal charges capacitor C7. Diode D3 completes that current path. The next alternation charges C9 and C8. D2, C7, and resistor R15 complete that current path. After a few alternations, the combined voltage in C9 and C7 charge C8 to twice the voltage in either capacitor. This voltage passes through R16, causing transistor Q1 to saturate and turn on Q2. When Q2 switches on, the ground on its emitter becomes connected to its collector. Since the right side of relay coil K1 connects (through switch SW1) to +13 volts, the relay "pulls in"—that is, the amplifier is switched in line. The "switched ground" on Q2's collector also grounds the bottom of R4 (up in the middle of the circuit). That shifts Q3 from switched "off" to switched "on," removing reverse bias on D5 and thus changing the amplifier's bias point from cutoff to class B/linear mode operation.

Don't fret if those last few steps sounded confusing. We'll discuss amps, biasing, and transistor theory in more detail later and it will make more sense.




**NOTE:**
**R2, R3 and R4 were combined to equal one resistance, which was then paralleled with R1. Those two paralleled resistances were then combined to equal $R_{TOTAL}$.**

*Figure 3. Equivalent circuit of Figure 1 or 2 as "seen" by its battery. The total resistance (R total) is DC representation of a complete transceiver. See discussion in text.*

## A Unique SWR Checker

If you're still with us technically, you're doing great. Now let's put some of our acquired knowledge about resistors and current paths to good use by homebrewing a unique Wheatstone bridge-type SWR checker.

What's a Wheatstone bridge, you ask? It's a classic laboratory test item originally used for measuring unknown resistance in a very precise manner. In our application, it forms the heart of a low-cost, easy-to-build, and self-referencing SWR monitor that also serves as a fail safe dummy load to prevent the SWR "seen" by your transmitter from ever rising above 100 ohms or 2:1. Those are the little tyke's good points. On the down side, the bridge absorbs RF power and must be disconnected from the antenna line after you're done testing, it's only suitable for low-power applications, and, since I've only had time to build one for

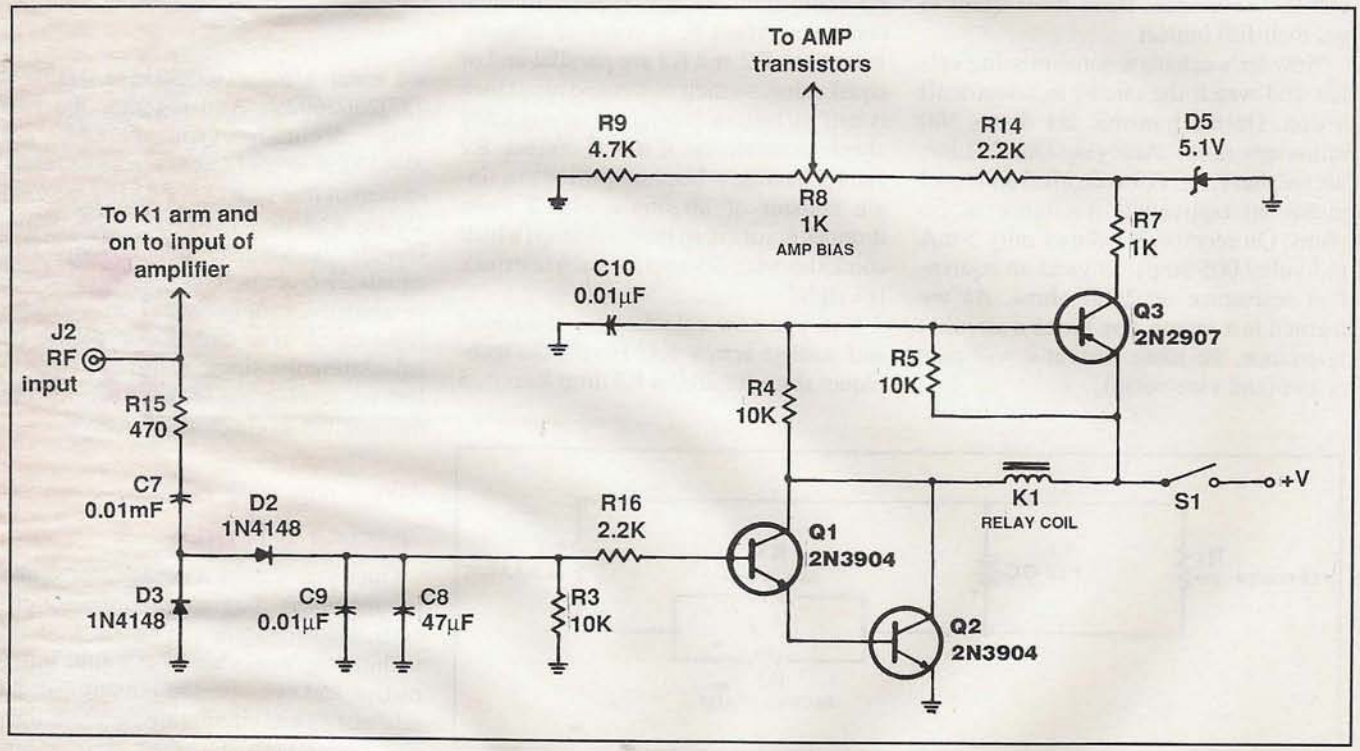



*Figure 4. This RF-sensing and automatic T/R switching circuit was sampled from a small solid-state power amplifier. A complete "how it works" discussion is in the text.*



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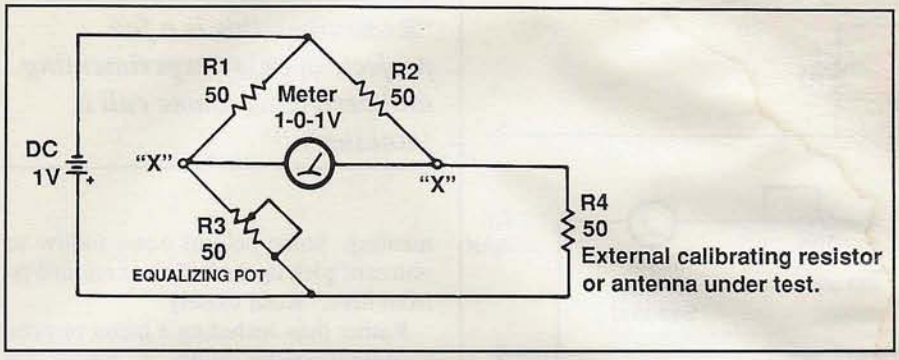


*Figure 5. Circuit diagram of an original Wheatstone bridge. The principle of operation is that the meter will read zero when the potentiometer, R3, is adjusted to the same resistance as R4, resistor or antenna under test.*

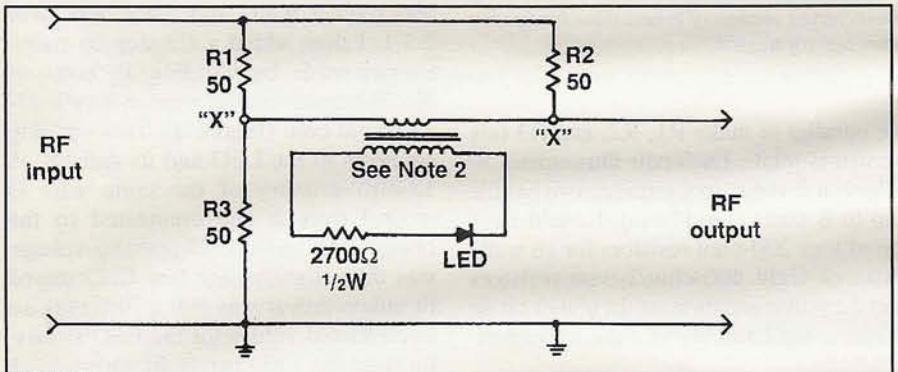


*Figure 6. Circuit diagram of Wheatstone bridge adapted for use as an SWR indicator, as discussed in text. This item is ideal for impromptu use with pocket-sized transceivers and portable antennas. Note that this version uses an LED instead of a meter as the readout device.*

HF use, you get the honor of perfecting it for 6- or 2-meter use.

How does a Wheatstone bridge work? Refer to Figure 5 and I'll zip through its basic concept of operation. First, let's assume that R1, R2, R3, and R4 are all equal values. Since we're talking about antennas, 50 ohms is a good value to visualize. Next, notice that R1 and R3 are wired in series and connected in parallel with R2 and R4 (which are also wired in series). A meter capable of reading voltage difference or current flow in either direction (in other words, a center-resting meter similar to an FM discriminator meter) is wired between left and right side resistors. A low amount of DC voltage is then applied to the bridge. If all four resistor values are equal, the bridge is balanced.

In this case, there will be no voltage difference or current flow between the two points "X," and the meter will read zero. If R4 (which will be our external calibrating resistor or an antenna under test) is more or less than 50 ohms, the meter will indicate that difference. We can recalibrate the meter's scale in ohms and read antenna resistance directly, or we can add a scale calibrated in ohms beneath a pointer knob attached to R3 and read antenna resistance on that scale. How's that? Suppose R4/the antenna is 25 or 100 ohms (a 2:1 SWR). Current will flow through the meter until R3 is readjusted to also equal 25 or 100 ohms. Suppose R4/the antenna is 37 or 75 ohms (a 1.5:1 SWR). Again R3 must be reset to an equal value for the meter to read zero difference. Neat, eh?

Space is now very short, so let's jump right to fine points of this bridge and how we'll use it for our needs.

First, R1, R2, R3, and R4 must be carbon composition-type resistors, not wirewound or metal film type (they exhibit


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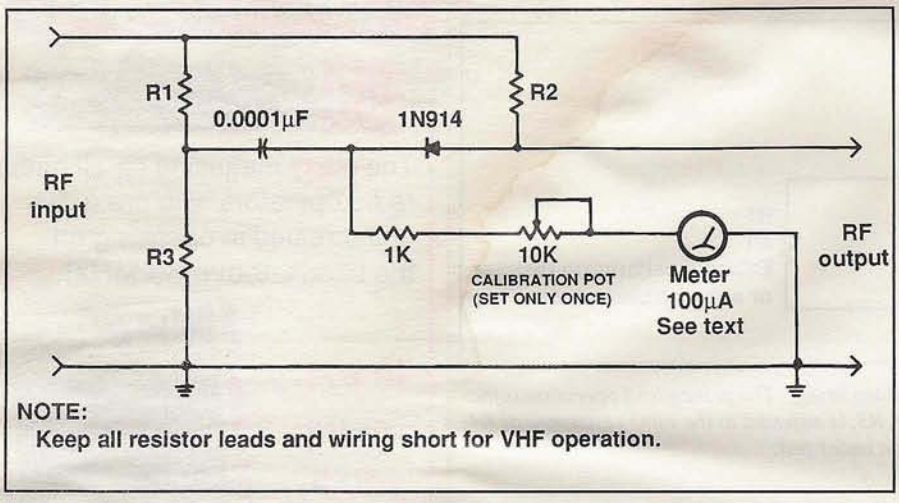


*Figure 7. An alternate idea applicable to the SWR metering section of Wheatstone bridge for use on 6 and 2 meters. See text for details.*

inductance and are unsuitable for RF applications). Each resistor must also be capable of handling half of your rig's output power. This rating can be "pushed" to near double if transmit/test time is held to only a few seconds, but be quick and careful to avoid burning out the resistors. I use two 100-ohm, 1-watt resistors wired in parallel to make R1, R2, and R3 (six resistors total). Each pair thus equals 50 ohms at 2 watts, so my bridge can handle up to 8 watts (see Photo). I could have used four 200-ohm resistors for 16 watts max or eight 400-ohm/1-watt resistors for 32 watts (and then used a higher range meter), but I ran out of time for experimenting. Some helpful notes follow so you can "pick up the ball and continue on from here." Read closely!

*"Remember, this is a fun project, so enjoy experimenting and perfecting (some call it 'dinking')."*

Rather than including a meter or even a potentiometer with a homebrew "ohms" scale, I went "po-boy style" by connecting an LED and a 27-ohm resistor between the two points "X." The idea worked, but only when transmit power was over 5 watts and SWR was over 2.5:1. I then added a 1:3 step-up transformer made by winding 36 turns of No.28 enamel-coated wire on an FT-37-43 toroid core (Figure 6). This winding connects to the LED and its resistor. A 12-turn primary of the same wire is wound over it and connected to the bridge's "X" points. Stepped up voltage was then slightly high (the LED stayed lit unless power was 500 milliwatts), so I substituted values for the LED's resistor until the LED barely lit with a 1.2:1 SWR and increased to full brightness at 1.4:1 (at 5 watts). The tweaked resistance value was 2700 ohms.

My 1:3 step-up transformer works great on HF, but not on VHF. Apparently an FT-37-43 has too much lumped inductance at 144 MHz. Amidon may have a suitable answer; alternately, I suggest direct-rectifying current difference and reading it on a 100- or 200-microamp meter (recalibrated in ohms) as shown in Figure 7. For reference, I also suggest initially checking out the bridge with a known-accurate SWR meter and an antenna tuner (plus antenna!). That way, you can vary SWR (via the tuner) and set the meter's 10-K calibration pot to work with your average SWR and power level. Remember, this is a fun project, so enjoy experimenting and perfecting (some call it "dinking").

## Till Next Time

Stay tuned for more good theory 'n practice and another mini project next month. Oh yes, the answer to receive resistance for Figure 1, 2, and 3 is 123.8 ohms. Hearty congratulations if you calculated it right. You're a sharp Tech! The question was sort of tough! 73,

—Dave, K4TWJ

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